GREAT AMERICAN LEVEES

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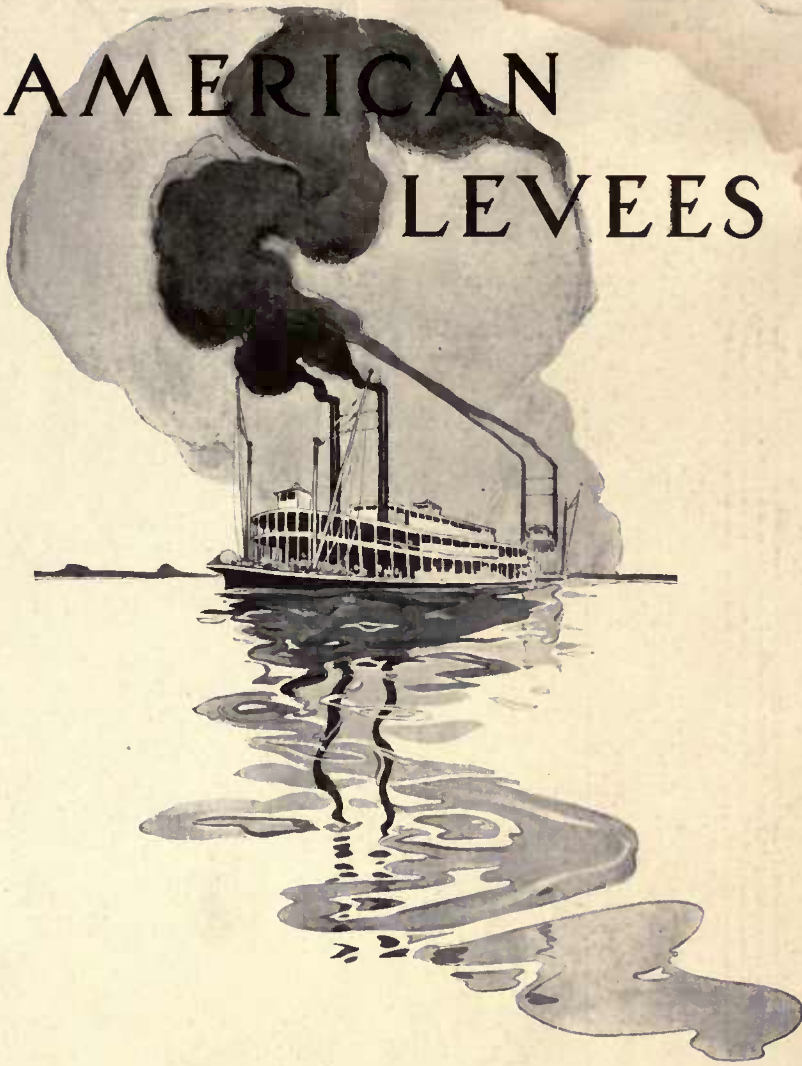

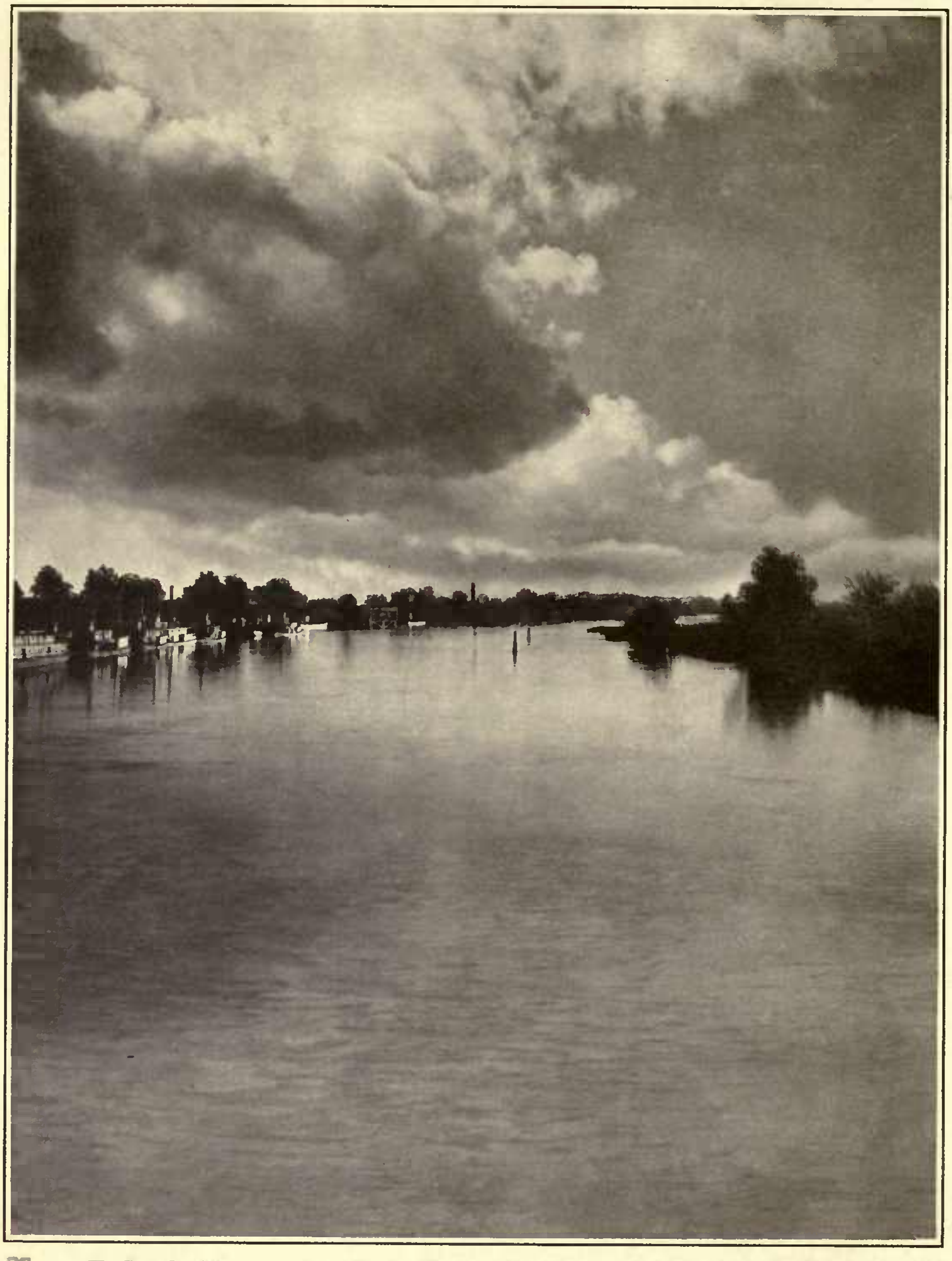

FROM SHASTA TO THE SEA

GREAT AMERICAN LEVEES

A
COMPARATIVE
REPORT *on* FLOOD
PROTECTION *in*
the MISSISSIPPI *and*
SACRAMENTO VALLEYS
MADE *for the*
WEST SACRAMENTO
COMPANY

by
HAVILAND DOZIER & TIBBETTS
Civil & Consulting Engineers
ISSVED *by*
WEST SACRAMENTO COMPANY
SACRAMENTO

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Presented to Benjamin Ide Wheeler

FOREWORD

RECLAMATION, *as it affects the great Mississippi and Sacramento Valleys of America, is a work involving many failures and with but few instances of complete success. It is a gigantic task that involves conservative engineering, the employment of the highest type of labor and the most modern, mechanical methods.*

In the Sacramento Valley the reclaimed lands are unusually fertile, and of great value for agricultural purposes; while the climatic conditions are of such an ideal nature that intensive cultivation is followed with the most surprising success.

Because of the uncertain and hazardous protection from flood waters in the past, these lands have not been available for settlement.

The West Sacramento Company entered the field of reclamation and progressive agricultural development of reclaimed lands with a deep appreciation of the difficulties involved. The responsibility of protecting its future settlers in the most complete manner from the flood waters of the affected districts was thoroughly understood and accepted by this Company.

To positively and satisfactorily accomplish the greatest success in work of this character, levees of the most thorough construction must be built. They must be of sufficient height and cross section and be protected from wave wash, seepage and current scour, in a manner consistent with the best practice; also drainage systems of adequate capacity must be installed.

All these features are engineering problems which the pioneer, with his limited data concerning the magnitude of flood conditions, could not successfully solve. This Company, from the time of entering the field and several years prior to any construction work, employed the best engineering and construction talent available. It never at any time allowed the question of expense to restrict or interfere with the design and construction of the finest and largest levee systems in the West.

In the Sacramento Valley great floods occur at long intervals, but they come so suddenly and with such little warning, that there is then no time or opportunity for studying methods which will successfully combat them.

Since California is a new country and examples of successful levee construction are of comparatively recent origin, it was thought by those directing the West Sacramento Company that it would be possible to learn much from older districts facing the same problems.

Therefore, in the Spring of 1912, when the Mississippi Valley, which contains the most extensive levee systems in the world, was visited by a flood of unprecedented magnitude, and it became evident that levee failures were imminent

in that section, the engineers of this Company were instructed to proceed at once to New Orleans, La.

Although this trip had been planned for some time, it was hastened on April 6th by news advising that the great St. Francis Levee, opposite Memphis, Tenn., had failed!

Messrs. P. A. Haviland and F. H. Tibbetts, the Company's experts, started immediately from San Francisco to the scene of danger. Beginning at the mouth of the Mississippi they traveled up the course of this river to its junction with the Ohio at Cairo, Ill. They made a first-hand study of every method pertaining to levee construction, levee protection, emergency work and levee failures along the entire route.

The results gained from this investigation are important. They are of public interest and should prove of direct value in the development of thorough and state-wide reclamation in California.

With the hope that the very complete investigations and reports of its engineers may be of service to every reclamation interest, "Great American Levees" is published and presented to you with the compliments of the West Sacramento Company.

H. W. Furlong

General Manager.

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Levee Construction and Emergency Work

THE Mississippi River has a drainage area over forty times as great as the Sacramento, but has a measured flood discharge only four times as great. The flood of 1912 was the result of an unprecedented combination of moderately high stages in all of the large tributaries, the upper Mississippi, the Missouri, the Ohio and the Red Rivers, caused by a series of unusual storms passing across the lower Missouri and Mississippi watersheds, and practically the whole of the Ohio watershed. It is significant that none of these tributaries reached anywhere near record stages. For example, the maximum stage in Ohio, at Cincinnati, in 1912 was nearly 18 feet lower than the extreme high-water mark, and in the Mississippi, at St. Louis, was nearly 7 feet lower than extreme high-water mark. If, as may occur at any time, all these large tributaries are at extreme flood stages simultaneously, then the Mississippi Valley will be visited by a far greater and more disastrous flood than that of 1912.

From the mouth of the Ohio River at Cairo, to the Gulf of Mexico, a distance of nearly 2,000 miles, record stages were exceeded in 1912 by from 1 to 5 feet, and would have been exceeded an indeterminate amount in excess of this, had not the levees generally failed. Had there been no failures, the flood would have crested at Cairo, about April 10th. The important levee failures occurred between March 30th and May 15th, the most serious being concentrated in the week between April 6th and 12th inclusive.

Methods of Levee Construction

The levee system along the lower Mississippi River, that is from the mouth of the Ohio down, is one of the most extensive in the world, comprising about 2,000 miles of levees and protecting some 25,000 square miles, or 16,000,000 acres of land.

The location of the principal levee systems is indicated on the accompanying map (Plate 1) taken from an article by Mr. A. L. Dabney, Consulting Engineer of Memphis, Tenn., published in the *Engineering News* of June 13, 1912.

Almost uniform climatic, topographical and geological conditions have made it possible for the engineers of the Mississippi River Commission to adopt a standard levee cross section from which there need be but little variation. This

FIGURE 1 — Standard government levee at Lake St. John, La. Levee 22 feet high with banquette on rear.

cross section has been developed by long experience and is expected to withstand the water to within 3 feet of the crown, for long periods without excessive saturation or change of forms, and to give unqualified protection under any normal conditions of foundation and materials of construction. It is not believed that in the 1912 flood there were any important failures in levees of the standard cross section, unless the water got higher than 3 feet below the crown, except through defective foundations. The standard cross section is shown on Section 1, Plate 2. It has an 8-foot top width, with 1 on 3 side slopes to the ground level on the water side, and on the land side, down to a point 8 feet from the top, at which point a banquette is added with a 1 on 10 slope for 20 feet, after which the slope is 1 on 4 to the ground level. (See Figs. 1 and 2.)

The borrow pits, wherever possible, are made on the water side with a berm of at least 40 feet, and at the inner edge are only 3 feet deep with a 1 on 2 side slope. They can be deepened toward the river, however, at the rate of 2 feet per hundred. Where it is necessary to place the borrow pits on the land side a berm is left of at least 100 feet. The base of the levee is always thoroughly cleared of trees, brush, grass or other foreign material and plowed, and sometimes the top surface, containing roots, removed. A muck ditch or exploration trench is dug along the base of the levee 5 feet in front of the center line, and back filled with strong, well-tamped material, in order that there may be

FIGURE 2 — Standard government levee.
Lower Tensas District at Alsatia Break. Spectators
standing on banquette at rear.

no continuous holes or lines of weakness in the foundation. The borrow pits are interrupted by traverses with a minimum top width of 10 feet and side slopes of 1 on 2. The traverses are left normal to the levee, at intervals of not more than 500 feet, to prevent the flow of a current along the base of the levee. (See Fig. 3.)

Nearly all construction work has been accomplished with teams and scrapers, or by hand work with shovels and wheelbarrows, using cheap negro labor. In the last few years, however, use is beginning to be made of drag-line excavators, steam shovels, and other dredging and excavating machinery.

The banquette, by adding dead weight to the rear of the levee, tends to counteract the otherwise unbalanced water pressure on the front, and thus prevent the upheaving of the foundation when the levee becomes saturated through long exposure. A similar effect, that of adding dead weight to the rear of the levee, is sometimes attained by the construction of secondary levees located some distance to the rear of the main levee, allowing the space between to fill with water, thus creating a counter-head. This principle is strongly advocated by Major Dabney, Engineer of the upper Yazoo Levee District, who also employs a somewhat heavier cross section with flatter slopes in the rear, as shown by Section 2, Plate 2. It is significant that this district is one of the two large districts

FIGURE 3 — Levee at Vidalia, La.
Eddy formed at location of traverse on berm. Sack revetment to prevent undermining.

(the second being the Pontchartrain District above New Orleans) in which there were no disastrous breaks in 1912.

For comparative purposes, there are also shown on Plate 2 the standard levee section proposed by the Dabney Commission and by the California Debris Commission for the main levee systems in the Sacramento Valley, as well as the sections of several well-known California Districts. It will be noticed that none of the California levees are provided with a banquette. It is probable that this is chiefly due to the fact that most of the large California levees are constructed with floating clam shell dredges which on account of the limitations of reach are unable to build banquettes on the rear. In general the rear slopes of such levees, if economically built, represent the slope at which the material dredged will stand, varying from 1 on $1\frac{1}{2}$ in sand to 1 on 4 in wet clay or adobe. The banquette is not needed in California as it is along the Mississippi River, because the floods are of much shorter duration and the levee section seldom has time to get completely saturated. The chief purpose of the banquette is to add dead weight to the rear of the levee in order to balance the hydrostatic head on the front, an object which becomes necessary only when the levee cross section approaches saturation.

The muck ditch or exploration trench should be in more general use in California, especially in levees built in the tules. Where an unbroken top layer

FIGURE 4—Edge of great crevasse at Alsatia, La. One of the largest and most disastrous breaks in the history of the Mississippi River. Break about 5000 feet long; water running about 15 feet deep. Flooded the entire Tensas Valley.

of tules is left it makes a porous strata at the base of the levee which increases seepage underneath, tending to saturate the levee, to increase the danger of sloughing, and to increase the cost of pumping seepage water. Where levees are constructed of sand, on sand or sandy silt foundations, as frequently found along the Sacramento River, then all that may be necessary is a thorough cleaning by hand, and possible plowing of the surface to prevent a line of weakness at the base of the levee.

Levee Failures

Along the 2,000 miles of levee of the lower Mississippi River there were 22 breaks aggregating in length about 20 miles. This is counting as two breaks the failure of the upper St. Francis levee which is intermittent and unfinished. Flood waters from these breaks flooded over 5,000,000 acres or about $\frac{1}{8}$ of the total area which they were designed to protect. The only important break on the east side of the Mississippi River occurred near the mouth of the White River, and flooded over 800,000 acres, or about $\frac{1}{5}$ of the total area under levees in Mississippi.

A great percentage of the large breaks did not occur until the levees were actually overtopped, and in many cases the levees were held by temporary

FIGURE 5 — Rear edge at south end of big crevasse at Alsatia or Salem, La., about 50 miles above Vicksburg, Tenn. Break occurred at junction of old and new levee. Levee was 22 feet high and holding 17 feet of water. Break occurred by a sand-boil suddenly appearing at the rear toe. The levee was considered safe. A stream of water 2 feet in diameter was reported to be running through the sand-boil, just prior to the collapse of the levee.

emergency methods, until water was as much as 2 to 3 feet above the natural crown. The levee failures in general were from four different causes, as follows:

1. From defective foundations, causing sand-boils or blow-outs.
2. From insufficient cross sections, permitting saturation and sloughing of the land side face.
3. From overtopping.
4. From wind action causing waves to undermine and destroy portions of the levee.

Foundation Failures

Most of the levees have been brought up to their present grades by successive enlargements. Frequently the earlier construction work was completed with little or no attention to properly clearing the ground to be occupied by the base of the levee. This has resulted in a partial line of weakness at the foundation, allowing excessive seepage. In other places the levee even though carefully constructed may be underlaid with pockets or strata of porous material or may have the base weakened by holes from burroughing animals. In any of these cases when the levee is long exposed to a considerable head of water,

FIGURE 6—Levee at Vidalia, La., opposite Natchez, Miss. Saturated rear slope is beginning to slough off. Water within 1 foot of crown of levee which has been raised 3 feet by earth topping. Sloughing in rear of levee near center of view. Contractor's emergency camp in background.

seepage finds its way through in increasing quantities and may make its appearance in concentrated form on the banquette, at the rear toe of the levee, or a considerable distance beyond the rear toe of the levee. When the seepage becomes concentrated, and especially if it is muddy, indicating that it is washing material from the levee section, it is a serious indication of approaching failure. "Sand-boils" or "blow-outs" are thus caused. If the seepage is allowed to continue until a well-defined stream comes through the rear of the levee, a hole is soon washed completely through, and the levee caves in with disastrous results. Where the levees are comparatively low and carefully patrolled, this is sometimes checked by dumping in material, preferably clay, on the outer slope which may be drawn in to the weakened portions, thus checking the seepage. In general, however, the best method of treatment is to surround spots where seepage concentrates in an alarming fashion, with a wall of earth, or to encircle or loop them with sacks of earth. The retaining work must be carried up to a sufficient height to overcome the head of water on the outside. When a leak of this sort appears at the base of the levee or on the rear slope, accompanied by the flowing or boiling up of sand, no time should be lost in commencing emergency work. (See Fig. 5.)

Where, due to defective foundations, sand-boils are numerous, the most effective method of treatment is to enlarge the banquette, or to build sub-levees.

FIGURE 7 — Brush and sack revetment, Blytheville, Ark. Here the sack topping is fully 2 feet above the levee. The slope has become so saturated that the heavy brush and sack revetment was applied to keep it from sloughing away. (By courtesy of Mr. A. L. Dabney.)

However, this is seldom practical in an emergency, on account of the limited time available. Where there is a more impervious surface and the tendency at an incipient blow-out is to raise the surface with comparatively little seepage, a remedy may sometimes be found in the application of dead weight to balance the hydrostatic head communicated through the weakened strata under the base of the levee. This can be done by covering the weakened spot with a porous material, such as straw or brush, and weighting down with sacks of earth. This may hold down the threatened portion and at the same time allow the passage of seepage water, but with such reduced velocity that further erosion is checked.

Sloughing of Rear Slope

This is a common method of failure in levees of deficient cross section and drainage, after long periods of exposure. It is particularly pronounced in levees which have been enlarged by adding material on the rear slopes. Where such enlargements are made, great care should be used to secure a perfect bond between the old and the new work. If the new material is more impervious or is more thoroughly tamped or packed than the old levee, then the hydrostatic pressure accumulates against the new layers so that sloughing is apt to occur along the junction between the old and new work. In general, when the line of

FIGURE 8—Sack revetment and sack topping near Memphis, Tenn. (By courtesy of Mr. A. L. Dabney.)

complete saturation passes through the levee so that seepage appears in any considerable amounts on the rear face, sloughing is apt to occur. (See Fig. 6.)

It is believed that more thorough drainage of the levees would check this wide-spread tendency along the Mississippi River. There are many cases in which a line of tile is placed underneath the rear toe and many others in which a small hand ditch is located at or near the rear toe. Both of these methods are designed to collect seepage water and lead it away from the levees to the adjacent fields. When properly constructed, drainage of this sort is very efficient in preventing the saturation of the rear slope. It may even be used with highly beneficial results as emergency work, when it is evident that the rear slope is becoming actually saturated. When sloughing occurs, the most common emergency work is to add dead weight near the base of the rear slope, usually by first covering the saturated surface with a coarse layer of brush or straw and then weighting with sacks of earth, sand, or other convenient material. (See Plate 3 and Figs. 7 and 8.)

Where brush or small poles are used, they should be laid parallel to the slope in order to permit the passage of seepage water without further erosion. This work is always exceedingly difficult, because the saturation of the levee and frequently of the adjacent land prevents the use of teams and even makes it unsafe to borrow earth in the immediate vicinity. In a long continued flood,

FIGURE 9—Earth topping on levees at Vidalia, above
Natchez, Miss.; levee raised 2 feet with fresh earth placed with wheelbarrows.
Wash-boards to protect from wave action.
Crown width 2 feet.

where the levees tend to become saturated with resultant sloughing, the danger may be greatly increased by cloudy weather and constant rains, which prevent the rear slopes from drying out.

Overtopping

When an earth levee is actually overtopped, its failure is certain within a few hours. When it becomes evident that there is danger from this source, there are a number of methods of emergency work used for raising or "topping" the levees. The principal methods are shown on Plate 4. The levees along the Mississippi River usually have a top width not exceeding 8 feet which does not permit a raise exceeding about 3 feet as a maximum. When there is sufficient time, and the rear slope and adjacent ground is not too greatly weakened by saturation, the best method is to top the levees with earth taken from borrow pits beyond the inner toe of the levees. This work can be most cheaply done with teams and scrapers. In many cases, however, the saturation of the rear slope makes it dangerous to work with teams, and hence the topping has to be done by hand, or with wheelbarrows. In other cases observed, the land to the rear was so saturated that material had to be borrowed from the banquette or rear slopes. Even where the top width was as narrow as 8 feet, the topping was

FIGURE 10—Levees of lower Yazoo District near Brunswick, Miss., topped with sacking, partially backed with earth (water has fallen as a result of the Alsatia break).

extended to a height of 3 feet as shown on Section 1, Plate 4, giving the fresh material 1 on $1\frac{1}{2}$ side slopes, and a 2-foot crown width. (See Fig. 9.)

A number of variations of this method are shown on Plate 4, in some of which sacks of earth are employed, permitting the use of a smaller amount of material and more rapid raising of the levees. The sacks placed on the water side are also less susceptible of injury from wave wash than the surface of the new earth topping. (See Fig. 10.)

Wash-boarding was extensively used also, as shown in Section 5, backed with a small section of earth fill. The wash-boards were usually cheap 1-inch lumber, but afforded some protection against wave wash. (See Fig. 11.)

Frequently the topping has to be done with material borrowed from the old levee near the crown. In such cases it is plowed, if possible, and the earth taken from the rear edge of the top. Loose material used as a core between tiers of sacks should be thoroughly tamped. The timber bulkhead backed by earth is the cheapest method, and answers satisfactorily where the levee does not require raising more than a foot or so. Where a rise of 2 feet or more is anticipated, however, and especially where it is impossible to work teams and scrapers, dependence must be placed upon the more expensive sack method, with or without an earth core.

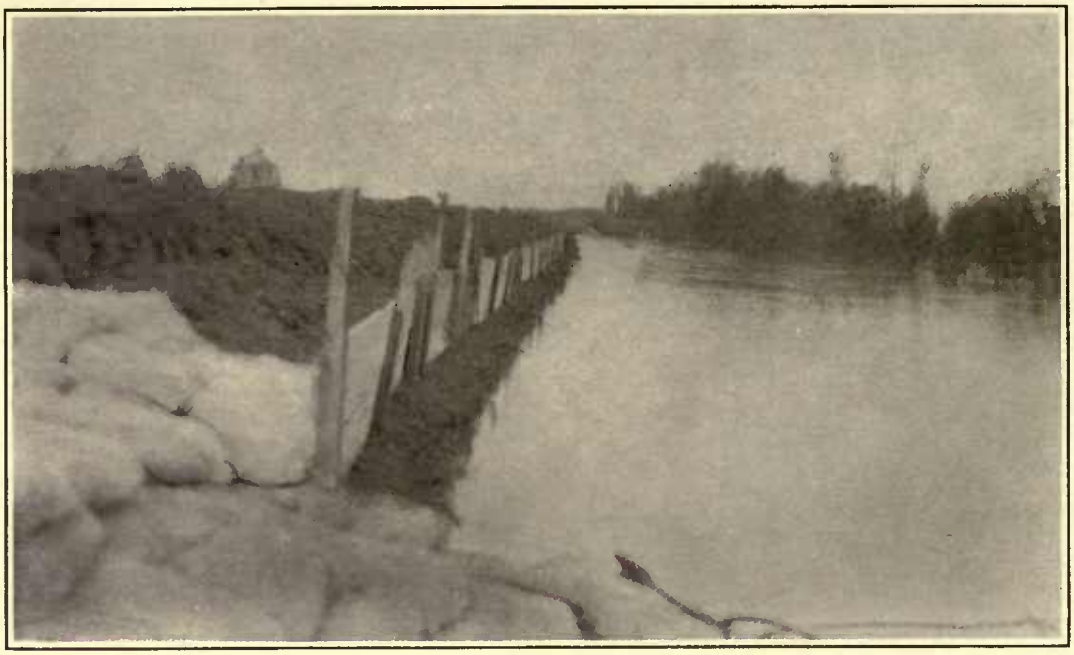


FIGURE 11—Levees of Fifth Louisiana District above Natchez, topped with wash-boards, backed with earth. 1-inch boards nailed to 2 x 4 stakes. Barge of Mississippi River Commission in background placing wash-boards from berm. Sack revetment in foreground.

One advantage of the use of sacks is that they can be filled from convenient points and transported, frequently by barges, to the site of the work, thus obviating the necessity of further weakening the original cross section by borrowing material for topping at the immediate vicinity of the work.

Any of these temporary methods of topping levees with such a narrow width are not apt to be efficient in a prolonged flood. That they can hold, however, for a limited time is well shown by the fact that the topping raised the water at the Reel Foot, lower St. Francis and White River levees 1 foot or more above the crests before the levees broke. On the upper St. Francis levees the water was about $1\frac{1}{2}$ feet above when the breaks began. On the upper Tensas District in Arkansas, the levees were actually held till the water was $2\frac{1}{2}$ feet above the top and until the temporary work itself was finally overtopped. (See Figs. 12 and 13.)

It would seem that under conditions obtaining in the Sacramento Valley, methods of topping might be more useful than along the Mississippi because the floods are of much shorter duration, and the levees commonly have a much greater top width. Against these advantages, however, along the Sacramento River is a swift and uncertain rise, giving little time for emergency work; and along the back levees in the flood basins is the very great danger from wave wash.

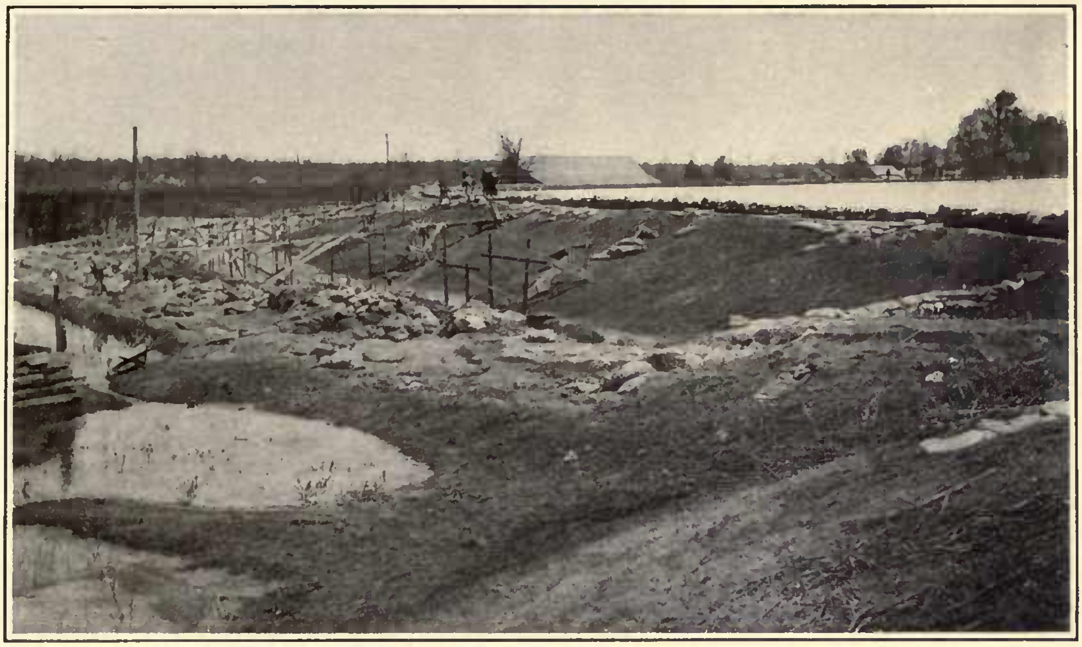


FIGURE 12—Sack topping, Blytheville, Ark.
Water reaching the sack topping. (By courtesy of Mr. A. L. Dabney.)

Wave Wash

The tendency for failure from wave wash appears in general to be much less along the Mississippi than along the Sacramento River. The Mississippi River levees, chiefly because of the shifting channel and caving banks, are generally located a considerable distance back from the river bank, and as the berm is covered with a dense growth of trees and underbrush, there is little exposure to wave wash. The river is so wide that constant erosion from steamer wash experienced along the Sacramento River is not evident along the Mississippi River. In California many of the heaviest and most costly levees are back levees located in the flood basins, which during winter storms may be exposed to tremendous wave action for many hours. The Reel Foot levee, near Hickman, Kentucky, appears to be the only important failure along the Mississippi River in 1912 from wind action. This levee failed with the water 1 foot above the natural crown from waves undermining the sack topping. There were many places, however, where the levees were located close to the river bank or the berm had been cleared, in which emergency work, to guard against wave wash, had been placed. The two methods in most common use are shown in Sections 1 and 4 on Plate 5. The sack protection is considered much more efficient, though more costly, than the wash-boards. (See Fig. 14.)

Vertical wash-boards, if exposed for any length of time, will be undermined

FIGURE 13—Lower St. Francis levee 10 miles below Memphis, Tenn. Topped with double tier of sacks. This levee held till topping was actually overtopped.

by the action of waves breaking at the vertical face, projecting the force of the water downward at the toe of the protection work. (See Fig. 9.)

A number of other methods which have been used in California are also shown on Plate 5, in the order of their relative efficiency. Probably the commonest method used for emergency work is to cover the slopes with a layer of fibrous material, such as tules, brush, straw, or any other convenient material. This mat is held in place by light chicken wire mesh staked at irregular intervals to the levee face with sharpened sticks having projecting nails to hold the wire mesh and fibrous mat close to the surface of the levee. Willow poles with projecting branches can also be conveniently used for staking down the mat. In any work of this nature an efficient patrolling system is absolutely essential, as any portion of the levee face not protected may cause failure in a short time.

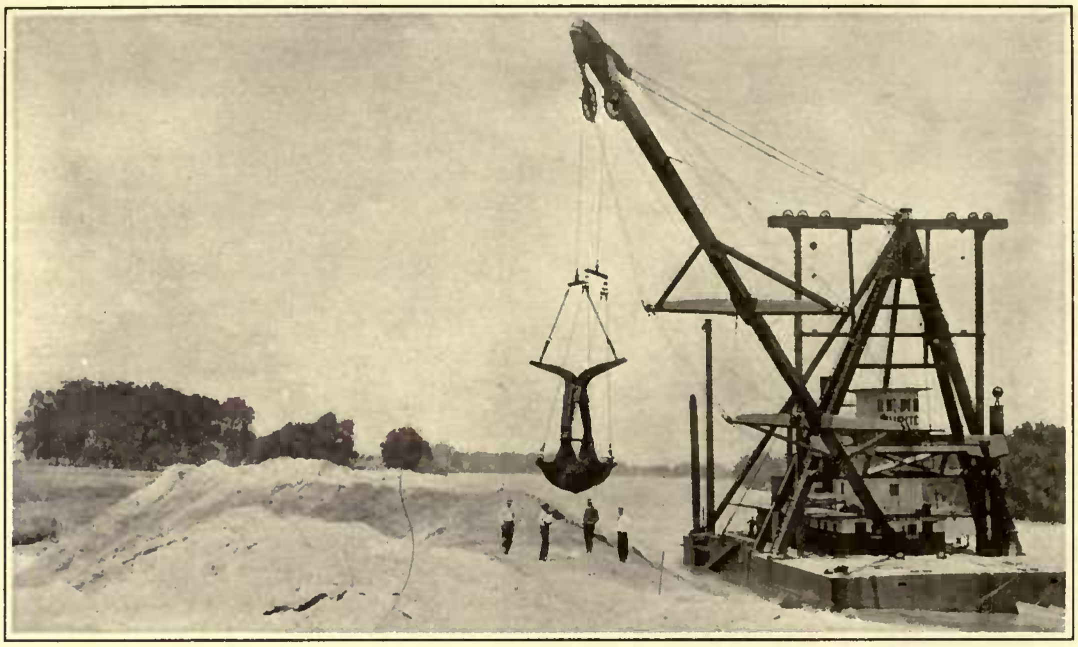
General Comment on Mississippi River Flood Control

The situation during the 1912 flood along the lower Mississippi seems from the superficial view-point of the writers to be somewhat discouraging. In any great river system with tributaries coming from different watersheds, the maximum floods occur only at long intervals, and only by combinations of high water, in all the principal tributaries. The condition of extreme high water occurring simultaneously in all tributaries has never been reached since the region was

FIGURE 14—Levees of the Fifth Louisiana District at sharp bend above Natchez. Sack revetment to protect against wave wash at point where levee is close to riverbank and completely exposed, due to absence of timber on berm.

settled, in either the Mississippi or Sacramento Valleys. It appears that in the great flood of 1909 at Sacramento, the American River was discharging not over $\frac{2}{3}$ of its maximum. As previously indicated, in the 1912 flood in the Mississippi, none of the tributaries were at extreme high-water stages. It is certain that if sufficient time were allowed, there will be greater floods both in the Mississippi and Sacramento Valleys than any so far recorded.

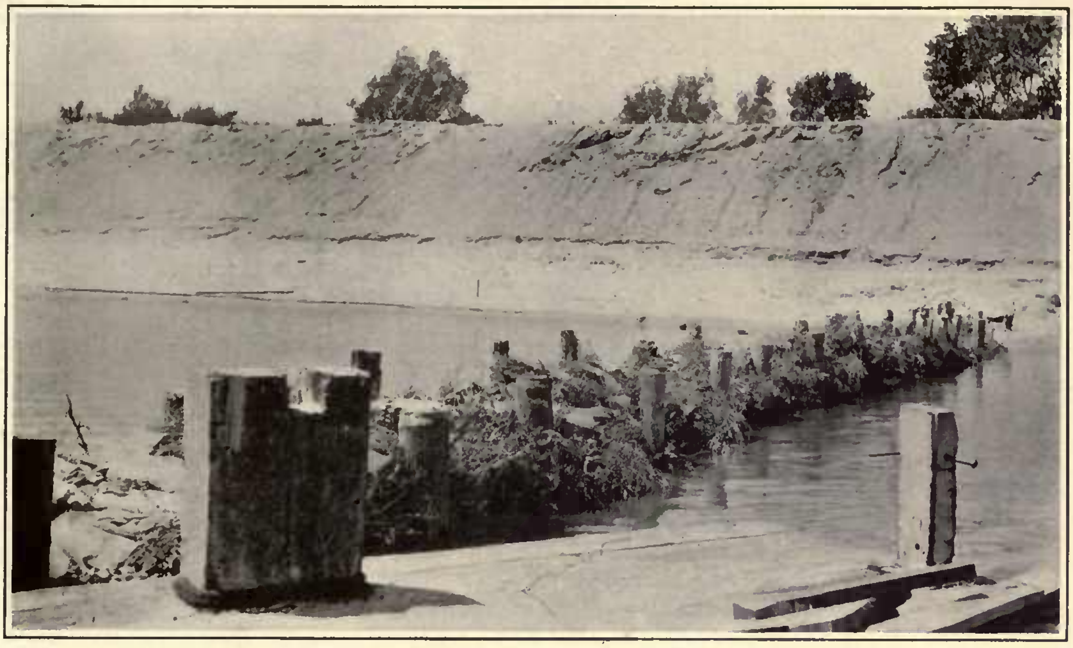
Engineers familiar with Mississippi River conditions estimate that had all levees been finished to grade, and 3 to 5 feet higher than planned, they would have been adequate to pass the 1912 flood. These estimates in the main, however, appear to emanate from Engineers who are or have been in some way interested in the work of the Mississippi River Commission, and who feel called upon to defend the levee construction methods followed in the past. It is, of course, impossible for visitors, with as casual a knowledge of the Mississippi River flood problems as the writers, to make any suggestion regarding the ultimate method of treatment. To any one who saw the great crevasses along the Mississippi this spring, it seems incredible that the total amount of water could ever be confined in the levees of the main channel. At the time the writer saw the Alsatia break, which was but one of 20 or more large levee breaks, the water was flowing through about 12 feet deep and 5,000 feet wide. The difference of head at the upper end of



Dredge Jupiter completing river levee of Elkhorn Reclamation District. Finished levee 40-foot top width; 1 on 2 side slopes; height 20 feet, 7 feet above high water. Dredge Jupiter 168-foot boom, 4½-yard bucket.

the break, measured at a point some 20 feet back from the end, showed the water standing about 2 feet higher on the outside of the levee than on the inside. It was, of course, impossible to get anywhere near the center of the break. If the estimated velocity through the break were as low as 7 feet per second, there would be over 400,000 second feet escaping from this one point alone. Mr. Kerr of the Engineer office at Memphis estimated at the time that the total discharge passing Memphis was about 2,000,000 second feet. If 20 per cent of this amount were going through one break alone, it does not seem reasonable that all of the water going out through the entire 20 breaks could be confined in the levees, especially as there were only 3 feet of levee above water at the time, at the City of New Orleans. Perhaps, after all, the Mississippi Valley in order to secure permanent protection from floods will be compelled to resort to a great by-pass scheme similar to that proposed for California. As a matter of fact, this principle is already in operation in the lower Mississippi, as water escaping from the Mississippi River on the west side below the mouth of the Red River is by-passed through the Atchafalya River into Lake Charles and the Gulf, and does not go by New Orleans.

No levees observed in the Mississippi Valley, except those of the City of New Orleans, were so large or so substantially constructed as some which the

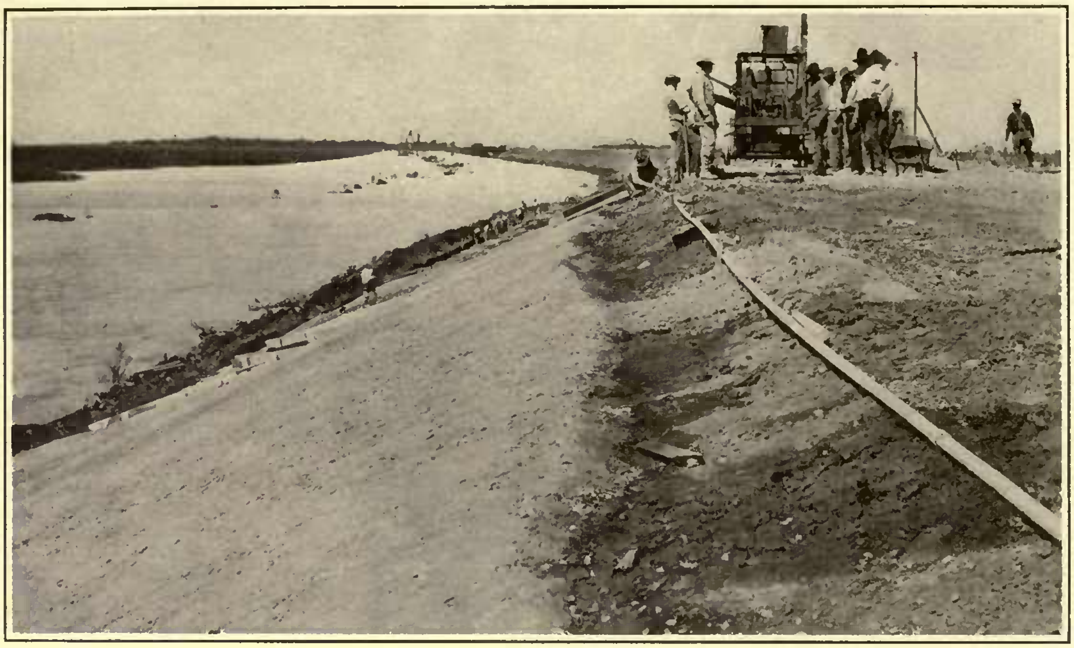


Finished river levee — West Sacramento Company. Levee 24 feet high, 80-foot top width, 7 feet above high water; side slopes 1 on 2 and 1 on 1½. Pile jetty in foreground designed for river contraction purpose to improve navigation; also effective in protecting lower toe of levee.

writers have seen in California. Methods of construction are very inferior and the unit costs of the levees proportionately higher. The great floating clam shell dredges in common use in California would probably create a sensation along the Mississippi River, and could certainly do most of the work much cheaper than it is being done under present methods. The results of all observations made tend to restore and confirm confidence in the higher, more substantial and more economically constructed levees in California.

Reclamation Work Accomplished in California

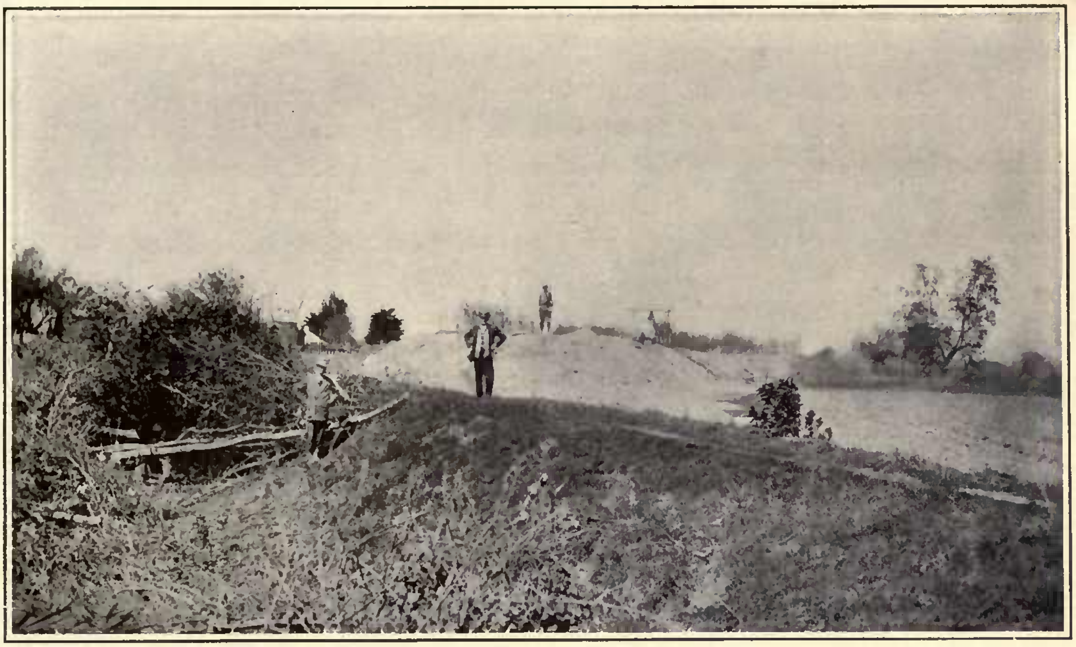
Up to a few years ago, the success of swamp land reclamation work in California was by no means assured. The reclaimed land was of very great value for agricultural purposes, but its usefulness was greatly impaired by the constant and growing uncertainty and danger from flood waters. The usual practice had been to completely enclose in levees, districts varying in size from a few acres to 50,000 acres. The levee systems had grown intermittently and irregularly from small hand levees to large dykes 10 to 15 feet or more in height. The pioneers had a very inadequate conception of the magnitude of the problems involved. Little use had been made of engineering skill or study, and the machinery in



Placing reinforced concrete facing on Lisbon back levee.
This levee will form the north levee of the Netherlands. Facing is of reinforced concrete $4\frac{1}{2}$ inches thick, resting on sheet piling at the lower toe and extending 5 feet above the high-water mark. Levee section 23 feet high; 15-foot top width; 1 on $2\frac{1}{2}$ side slopes; Dredge Lisbon in background.

use was of insufficient capacity to properly construct the necessary levees. The location, design and construction of most of the reclamation work were costly and inefficient.

The last decade has put an entirely different aspect upon this situation. Flood control problems have been studied thoroughly and scientifically and the best engineering talent available has been concentrated on the large reclamation districts. Heavy dredging machinery has been developed further in some lines than anywhere else in the world. The great clam shell dredges now in use in California are unsurpassed in capacity or length of reach. The levee cross sections have been gradually enlarged and improved and construction methods perfected, until it is doubtful if there are any larger or better levees anywhere. As compared with larger river systems, like the Mississippi for example, the maintenance of river levees is much easier in the Sacramento Valley, because of the much briefer duration of the floods, which are hardly long enough to permit of the saturation of the levee sections. On the other hand, the back levees located in the flood basins in many cases have a terrific exposure to wave wash during the winter storms. The growth of willows is generally encouraged on back levees, and climatic and other conditions are so favorable that where



River levee of Reclamation District No. 70 (Alameda Sugar Company). Dredge Neptune in background with section of finished levee. Top width, 20 feet; side slopes 1 on 2½; 6 feet above high-water mark. Height about 16 feet. Old levee in foreground.

there is a proper berm, it is frequently possible to get a dense covering in a short time. In some cases, however, this has been found to be inadequate, and at least one district (Lisbon) has faced its back levees with solid concrete, while others (West Sacramento Co.) are planning the same construction.

Most of the levees in the Sacramento Valley have grown in an irregular and intermittent fashion; many of them have been quickly destroyed by successive floods, and abandoned; but meanwhile new projects are constantly under way, so that it is impossible to give an accurate estimate of the amount of land reclaimed or partially reclaimed at any given time. The best estimates available at the present time indicate that the area of reclaimed land wholly in the flood basins and which could be said under normal conditions to be submerged with each moderate or large flood, is about 145,000 acres north of Sacramento, and about 110,000 acres south of Sacramento, making a total of 245,000 acres, or about 30 per cent of the total of 800,000 acres.

Principal Projects at Present Under Way in California

Reclamation work in the Sacramento Valley is proceeding at present at a wholly unprecedented rate. Actual construction work is being actively pushed on tracts aggregating over 150,000 acres, or nearly 20 per cent of the total. All

of these projects should be completed within the next two years. This means that the present period of say three years will see nearly 70 per cent as much land reclaimed and put under cultivation as the entire period preceding since the settlement of the valley. In addition to this, it seems certain that work will be begun immediately upon two more large projects, one in Sutter Basin and one in Yolo Basin, aggregating another 100,000 acres. If this be true, the present five-year period will more than double the total area of reclaimed land.

Future of Reclamation Work in the Sacramento Valley

Most of the projects under way, or proposed for immediate construction, are relatively large. Economical considerations make it more profitable to reclaim a large body of land than a small one. The recent organization of the State Reclamation Board and the comprehensive plan of the California Debris Commission insure future reclamation, following an orderly and legitimate plan, best adapted to the ultimate development of the vast resources of this region. The large reclamation districts are employing the best engineering and executive talent available, and under a broad and far-reaching financial policy are insisting upon the most thorough and substantial construction work. The disastrous mistakes of the past are not being repeated. The reclaimed lands are being provided with transportation facilities and are being rapidly settled and put under intensive cultivation.

The work of reclaiming the balance of the rich swamp lands is proceeding so rapidly and the future is so full of promise that the next decade should see practically all of this land under cultivation. Too much credit cannot be given to the men behind the great projects now nearing completion, who, in the face of previous disasters, have staked vast fortunes on the transformation into an empire, of a wilderness of tules.

Respectfully submitted,

HAVILAND & TIBBETTS.

West Sacramento, Cal.,
November,
Nineteen Hundred and Twelve.

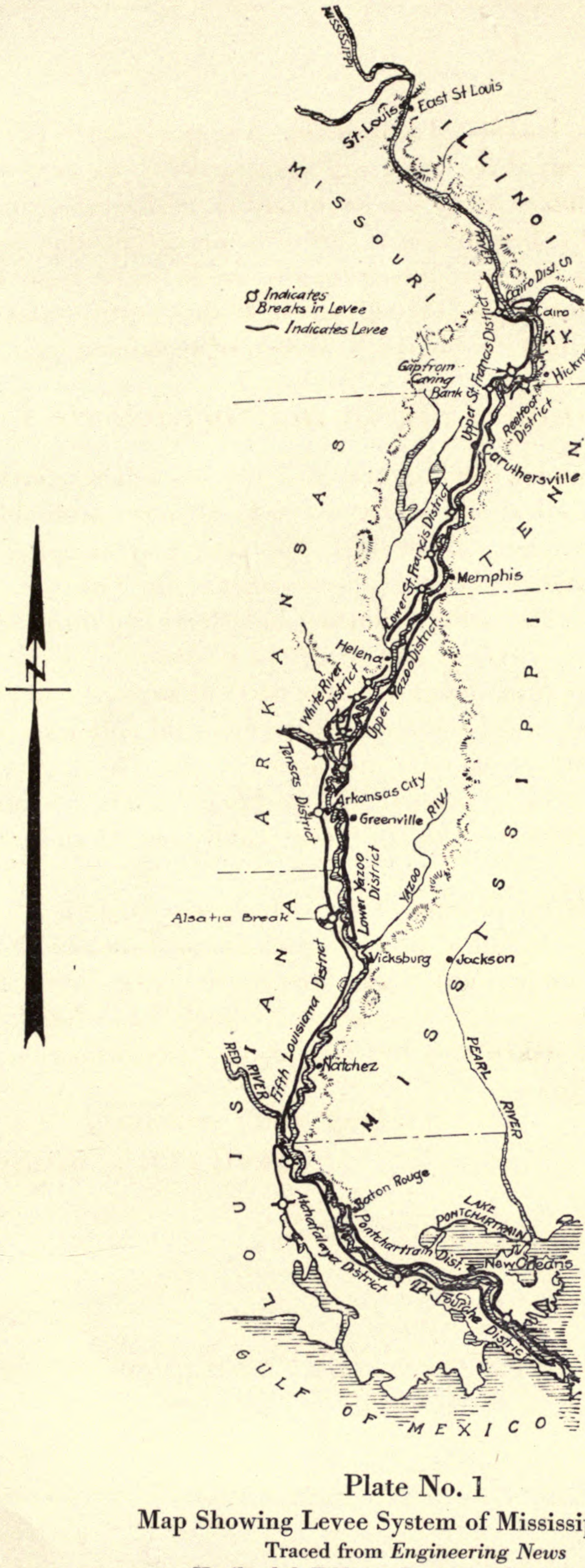


Plate No. 1

Map Showing Levee System of Mississippi River

Traced from *Engineering News*

Haviland & Tibbetts, Engineers, San Francisco

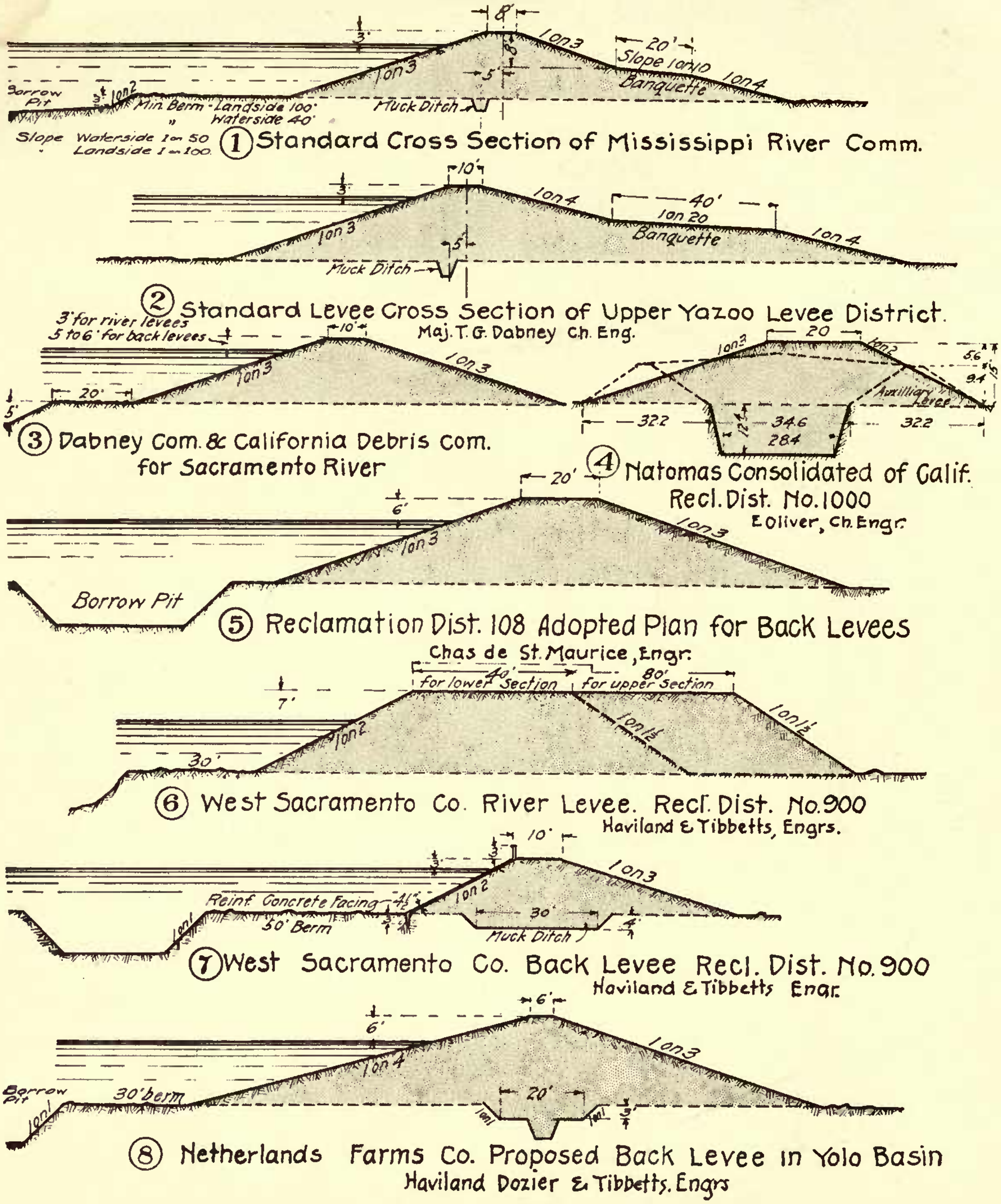


Plate No. 2

Standard Levee Cross Sections Used in Mississippi and Sacramento River Valleys

Haviland & Tibbetts, Engineers, San Francisco

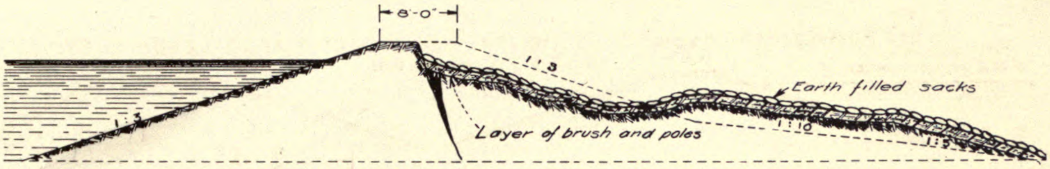


Plate No. 3

Showing Method of Protection from Sloughing

Copied from *Engineering News*, Article by Arthur Hider
Haviland & Tibbetts, Engineers, San Francisco

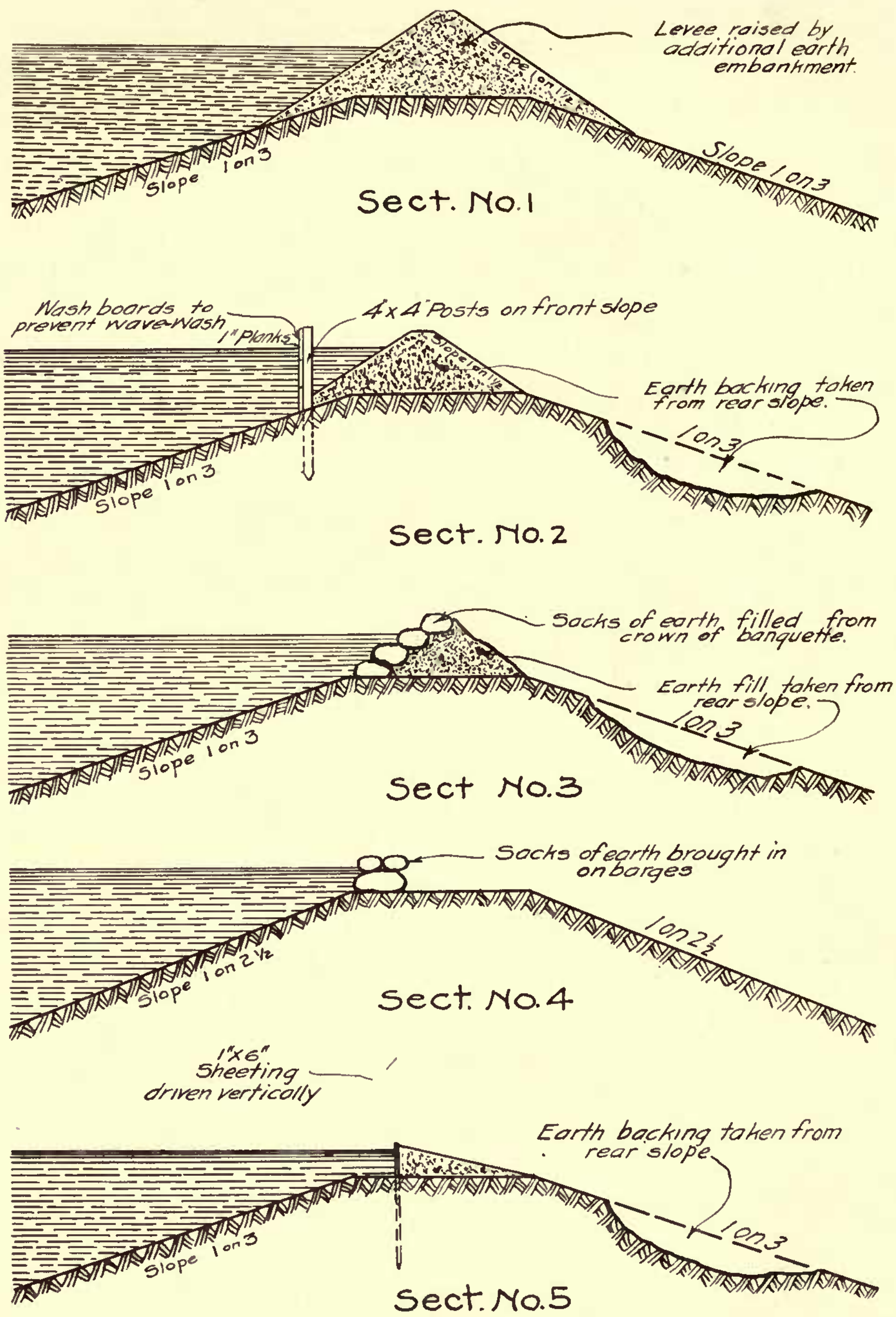
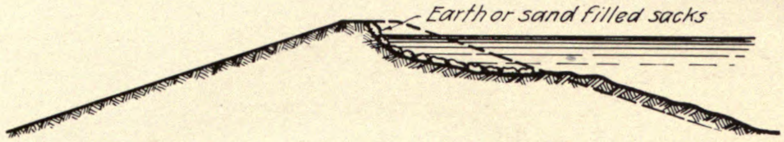


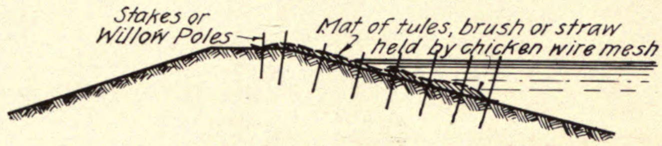
Plate No. 4

Methods Used to Prevent Overtopping of Levees

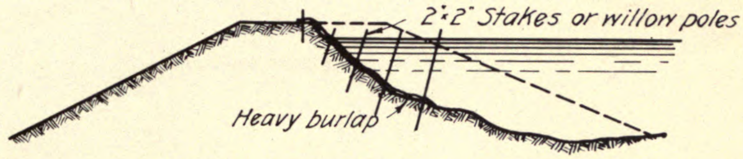
Haviland & Tibbetts, Engineers, San Francisco



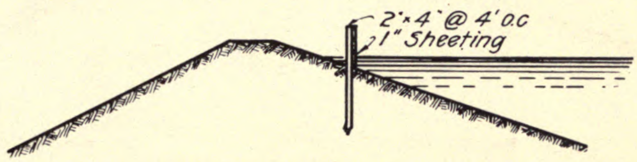
Section No. 1 SACK PROTECTION



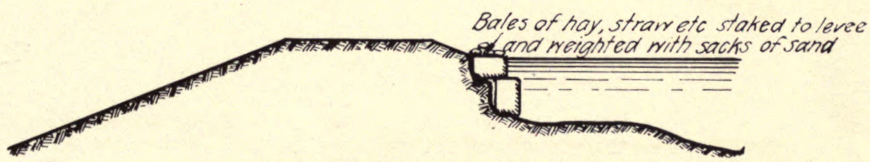
Section No. 2 BRUSH PROTECTION HELD IN PLACE BY STAKES



Section No. 3 BURLAP PROTECTION HELD IN PLACE BY STAKES



Section No. 4 1" WASH BOARDS SPIKED TO LIGHT STAKES



Section No. 5 PROTECTION BY BALES OF HAY OR STRAW

Plate No. 5

Methods of Protecting Levees Against Wave Wash

Haviland & Tibbetts, Engineers, San Francisco

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